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Management of incinerator residues in Flanders (Belgium) and in neighbouring countries. A comparison

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Abstract

This paper covers the Flemish legislative tools concerning the management of bottom ash, fly ash and APC residue from municipal waste incinerators, with respect to their contamination with heavy metals. The situation in Flanders is compared to the one in the Walloon region, The Netherlands, Germany and France.

Waste management in the countries considered differs on the level of available management options, of leaching tests and of limit values. To make an indicative comparison of leaching tests and limit values in the different countries, leaching tests were carried out on bottom ash and fly ash, and the results are compared to the relevant limit values for recycling and landfilling of the different countries.

The comparison of legislations as well as the leaching results show that discrepancies in waste management between the different regions and countries exist. Recently, European limit values for landfilling became available. European legislation on recycling, however, has not been developed and urgently needs to be considered and drafted as the market for recycling can be expanding rapidly.

1. Introduction

In a municipal solid waste incinerator (MSWI) different types of residues are produced (Fig. 1), the most important being bottom ash, which amounts to 20–30 wt% of the original municipal solid waste. Boiler ash is collected in the steam boiler. To clean the flue gases, usually reagents such as $NaHCO_3$ or $Ca(OH)_2$ are injected in a dry or semi-dry scrubber. Fly ash is collected separately by an electrostatic precipitator or along with the reaction products and excess reagent on a fabric filter. This may be followed by an additional wet flue gas cleaning. In this paper, fly ash is defined as solid residue originating from flue gas cleaning with no other products added; air pollution control (APC) residue is the flue gas cleaning residue together with reaction products and excess reagent. The ashes mentioned all contain heavy metals (IAWG, 1997), the most important being Cu, Pb and Zn (Table 1). Volatile metals such as Pb and Zn are usually found in higher concentrations in fly ash and APC residue than in bottom ash.

These residues are in practice recycled or landfilled. Advantages of recycling are that no landfill space is needed and that the materials may replace useful raw materials, which should be otherwise mined. Recycling may be stimulated by a landfill ban or by increasing landfill taxes. Fig. 2 illustrates the increase over the period 1989–2000 of the total cost of the landfilling of hazardous waste in Flanders (OVAM, 2001a). The total landfilling cost more than quadrupled, due to an in-

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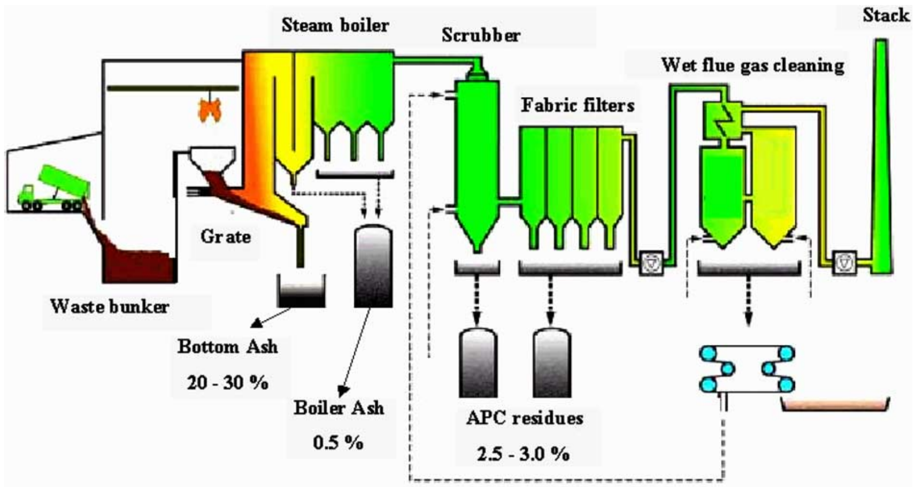

Fig. 1. Process scheme of a municipal solid waste incinerator.

crease of both the net price and the taxes. Recycling of incineration residues may be hampered due to considerations related to environmental safety and product quality.

In the first part of this paper, an overview is given of the legislation (both relative to recycling and landfilling) regarding incinerator residues in Flanders (Belgium) and in neighbouring regions and countries. Only inorganic compounds are included in the discussion. In the second part of this paper, the results of different leaching tests on bottom ash and fly ash are presented and compared to the relevant heavy metal leaching limit values of the different countries, in order to compare the different national legislations.

2. Overview of leaching tests

Leaching limit values and leaching results depend on the leaching test performed. The formally required leaching tests in the different countries are presented with focus on type, duration and L/S ratio. The type of leaching test refers to either column leaching with equilibrium not necessarily achieved or batch extraction test where equilibrium is assumed to have been reached.

Table 1
Heavy metal content of MSW residues (mg/kg dry matter) (IAWG, 1997)

	Bottom ash	Boiler ash	Fly ash	APC residue
As	1–200	20–60	40–300	20–500
Ba	400–2500	2000–3000	300–3000	50–14000
Cd	1–70	20–1300	50–450	140–1400
Co	20–50	20–200	10–90	1–300
Cr	20–3000	200–1000	140–1100	70–600
Cu	300–8000	500–1000	600–3200	10–2400
Mo	2–300	20–40	15–150	2–40
Ni	100–600	100–1500	60–260	20–700
Pb	100–14,000	1000–35,000	5300–26,000	2500–22,000
Sb	10–400	200–1000	260–1100	80–1100
Se	<10	10–100	1–30	1–30
Sn	2–400	200–700	550–2000	300–1400
Zn	1000–7000	5000–50,000	9000–70,000	7000–50,000

2.1. NEN7343 and prEN14405 column tests

For the NEN7343 test a column (20 cm length, 5 cm internal diameter) is filled with material, which was previously crushed to particle size <4 mm. The column is percolated with distilled water (acidified with concentrated HNO_3 down to pH 4) from bottom to top with a maximum water flow of 2 cm/h. The eluate is collected in several fractions depending on the total liquid to solid ratio (L/S) that needs to be reached. When the total L/S has to be 10, seven fractions are collected corresponding with L/S of 0.1, 0.1, 0.3, 0.5, 1, 3 and 5. The test takes about 3 weeks. When the total L/S has to be 1, only the first four fractions are collected. The leachate fractions are filtered over a 0.45 μm membrane and conserved for analysis. The metal concentrations in the consecutive fractions are summed to obtain a cumulative leached concentration.

The draft prEN14405 procedure is similar to the NEN7343 column test but the total L/S is 0.1. The single leachate fraction of the EN test equals in fact the first fraction of the NEN test.

2.2. DIN38414-S4, EN12457/4 and NFX31-210 extraction tests

In the DIN test, 20 g of material crushed to particles <4 mm, is leached in 200 ml of distilled water (L/S = 10) for 24 h while agitating. The slurry is then filtered over a 0.45 μm membrane to give a leachate, which can be analysed.

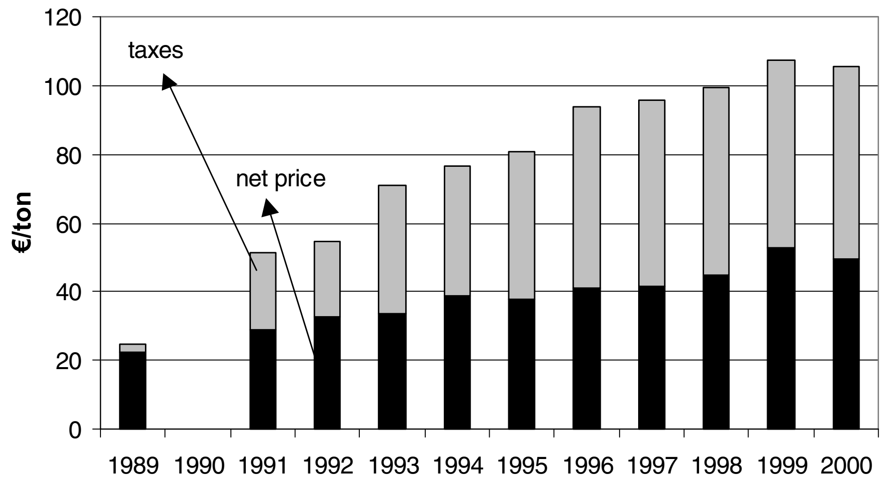

Fig. 2. Evolution of landfill cost for hazardous waste in Flanders.

The EN procedure is similar to the DIN test.

In the NFX test, the material is leached for only 16 h, but the extraction is repeated two times reusing the residue on the 0.45 μm filter membrane ($L/S = 30$). The metal concentrations in the three leachates are summed.

3. Legislation and waste management in Flanders

In Flanders (population = 5.95 million), 67% of MSW was collected separately in 2001 (VMM, 2002). Eleven MSW-incinerators incinerated in 1999 ca. 900,000 tons of solid waste. This led to 200,000 tons of bottom ash and to 35,000 tons of APC residue and boiler ash (OVAM, 2001b). In 2001, 258,000 tons of bottom ash were produced (OVAM, 2003).

3.1. Recycling

The Flemish government has drafted a list of hazardous wastes according to European legislation. Bottom ash is not hazardous and can, from the legal point of view, be considered for recycling in construction applications on condition that the application complies with certain requirements. For inorganic compounds (e.g., heavy metals), limit values were defined in Flanders for the leaching concentration of granular material (Table 2), using the NEN7343 column test. These limit values are valid for granular materials with a density of 1550 kg/m^3 and which are applied in a volume with a height of 0.7 m. In other conditions, laboratory leaching results should be recalculated to immission values and compared to immission limit values for soil. When granular materials comply with the limit values, they can be used as such or as an aggregate in monolithic applications. Granular materials that do not comply with the limit leaching values for granular applications can be recycled in monolithic applications, provided that the immission concentrations, calculated from the laboratory results using the NEN7345 diffusion test, comply with the immission limit values for soil. Besides the environmental limit values, civil-technical requirements (grain size distribution, strength, etc.) have to be met as well. When both leaching and civil-technical limit values are complied with, utilisation is unrestricted with respect to isolation measures.

In practice, immediate recycling of MSWI-bottom ashes is not possible in Flanders, because the leaching limit values are exceeded for copper and occasionally for lead and zinc (OVAM, 2001b; Vandecasteele et al., 2002). Also the particle size distribution of bottom ashes does not comply with that specified in the Belgian technical description of building materials, which applies to all construction activities for the government. So bottom ashes either have to be treated before recycling or have to be landfilled.

Unlike the situation in The Netherlands and Germany, treatment of bottom ashes, such as magnetic separation of iron, non-ferro separation, sieving and crushing of particles >40 mm, is not standard procedure. In Flanders two main bottom ash treatment plants are in operation (OVAM, 2001b). One is a wet sieving system with a capacity of 165,000 tons/year and the other a dry sieving system with a capacity of 300,000 tons/year. The wet processing of bottom ashes has several clear advantages over the dry system in view of quality-assurance: the light organic fraction floats in the washing barrel and can easily be removed, soluble salts are readily washed out, the rinsing effect produces visual clean end-products, and a high sieving efficiency is obtained producing high quality granulates. Bottom ashes processed by the wet sieving system are separated into ferrous and non-ferrous fractions which can be recycled, a 0–0.1 mm sludge fraction which has to be landfilled, a 0.1–2 mm sand fraction which can be used as construction material (e.g., on landfills), and 2–6

Table 2
Limit values for recycling of waste as construction material in selected countries

Category	Flanders		Wallonia		The Netherlands			Germany									France	
	All	Granular	BA		Cat. 1	Cat. 2	BA	Z_0		$Z_{1.1}$		$Z_{1.2}$		Z_2		BA	V	M
Criterion	Content[a]	Leaching	Leaching		Leaching[c]			Content	Leaching	Content	Leaching	Content	Leaching	Content	Leaching	Leaching	Leaching	
Test	Destr.[b]	NEN column	DIN[d] extr.	NEN column	NEN column			Destr.[b]	DIN[d] extr.	Destr.[b]	[d] extr.	Destr.[b]	[d] extr.	Destr.[b]	DIN[d] extr.	DIN[d] extr.	NFX extr.	
L/S	–	10	10	10	10	10	10	–	10	–	10	–	10	–	10	10	30	30
Al	–	–	2000	2000	–	–	–	–	–	–	–	–	–	–	–	–	–	–
As	250	0.8	1.0	0.8	0.88	7.0	7.0	20	0.1	30	0.1	50	0.4	150	0.6	–	2	4
Ba	–	–	–	–	5.5	58	58	–	–	–	–	–	–	–	–	–	–	–
Cd	10	0.03	1.0[e]	0.03	0.032	0.066	0.066	0.6	0.02	1	0.02	3	0.05	10	0.1	0.05	1	2
Co	–	–	1.0	0.25	0.42	2.5	2.5	–	–	–	–	–	–	–	–	–	–	–
Cr	1250	0.5	–	0.5	1.3	12	12	50	0.15	100	0.3	200	0.75	600	1.5	2	–	–
Cr^{VI}	–	–	1.0[e]	0.05	–	–	–	–	–	–	–	–	–	–	–	–	1.5	3
Cu	375	0.5	20[e]	5.0	0.72	3.5	24	40	0.5	100	0.5	200	1.5	600	3	3	–	–
Hg	5	0.02	0.2[e]	0.02	0.018	0.076	0.076	0.3	0.002	1	0.002	3	0.01	10	0.02	0.01	0.2	0.4
K	–	–	–	1700	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mo	–	–	1.5	1.8	0.28	0.91	26	–	–	–	–	–	–	–	–	–	–	–
Ni	250	0.75	2.0[e]	1.8	1.1	3.7	3.7	40	0.4	100	0.5	200	1.5	600	2	0.4	–	–
Pb	1250	1.3	2.0[e]	2.2	1.9	8.7	8.7	100	0.2	200	0.4	300	1	1000	2	0.5	10	50
Sb	–	–	2.0	0.3	0.045	0.43	2.1	–	–	–	–	–	–	–	–	–	–	–
Se	–	–	–	–	0.044	0.1	0.1	–	–	–	–	–	–	–	–	–	–	–
Sn	–	–	–	–	0.27	2.4	2.4	–	–	–	–	–	–	–	–	–	–	–
V	–	–	–	–	1.6	32	32	–	–	–	–	–	–	–	–	–	–	–
Th	–	–	–	–	–	–	–	0.5	<0.01	1	0.01	2	0.03	10	0.05	–	–	–
Ti	–	–	20	2.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zn	1250	2.8	9.0[e]	4.0	3.8	15	15	120	1	300	1	500	3	1500	6	3	–	–
Br^-	–	–	–	–	2.9[f]	44[f]	44[f]	–	–	–	–	–	–	–	–	–	–	–
Cl^-	–	–	5000	6000	599[f]	8807[f]	8807[f]	–	100	–	100	–	200	–	300	2500	–	–
F^-	–	–	50	20	13[f]	102[f]	102[f]	–	–	–	–	–	–	–	–	–	–	–
SO_4^{2-}	–	–	10,000	4000	1136[f]	22,027[f]	22,027[f]	–	500	–	500	–	1000	–	1500	6000	10,000	15,000
Total CN^-	–	–	0.46	0.2	–	–	–	1	<0.1	10	0.1	30	0.5	100	1	–	–	—
Free CN^-	–	–	–	–	–	–	–	1	–	10	–	20	–	100	–	0.2	–	–
pH	–	–	7–12	–	–	–	–	5.5–8[a]	5.5–10[a]	5.5–8[a]	5.5–12[a]	5–9[a]	5.5–12[a]	–	–	7–13	–	–

All values are expressed in mg/kg dry matter for the sake of comparison, although formal values are sometimes in mg/l.

[a] Indicative values.

[b] Destruction in Flanders has to be performed with HCl, HNO_3 and HF; destruction in Germany is performed with Aqua Regia.

[c] The leaching values for granular material in The Netherlands are calculated from the immission limit values for judgment purposes, using default values in the conversion formula as proposed by KIWA (1999) and using the same parameters as in Flanders (material density = 1550 kg/m^3, height of used volume = 0.7 m).

[d] Formal limit values are expressed in mg/l but are recalculated to mg/kg by multiplication with the applied *L/S* ratio.

[e] Sum of Cd, Cr^{VI}, Cu, Hg, Ni, Pb and Zn has to be lower than 50 mg/kg dry matter.

[f] Other limit values apply for specific conditions.

and 6–50 mm granulate fractions for which certificates were obtained for use as granular material in foundations. The granulates have to be stored for ageing during three months prior to application. For the 2–6 mm fraction, a certificate was obtained for use as replacement of raw materials such as sand and gravel in concrete bricks (Jaspers, 2002). The dry sieving system produces fractions of 0–10, 10–22, 22–40 and 40–80 mm in addition to the ferrous and non-ferrous fractions (Cortvriend, 2001). The fractions of 10–40 mm have a certificate for use in underfoundation, but only for specific applications.

To date, a significant fraction of the treated bottom ashes in Flanders is recycled, mostly in Wallonia. The market in Flanders itself is still immature. This can partly be explained by the very low limit value for Cu in comparison with Wallonia and neighbouring countries and by the only recent emergence of the wet sieving technology. In time this market is expected to grow substantially (Vrancken et al., 2000). In 2001, 54,000 tons of bottom ashes were exported to The Netherlands and 17,000 tons to Germany (OVAM, 2003).

3.2. Landfilling

When incinerator waste cannot be recycled, landfilling is the only option. The criteria for disposal of wastes are specified in the legislation. Fly ash and APC residue from waste incineration are hazardous wastes and have to be disposed of in category-1 landfills, which are landfills for the disposal of non-reactive hazardous wastes and for non-hazardous wastes of mainly inorganic composition. The leachability of heavy metals, following the DIN38414-S4 leaching test procedure, has to comply with the limit values given in Table 3. If the waste does not comply with these leaching limit values, immobilisation of the waste with additives such as cement has to be applied. If the best available technology for immobilisation does not produce a result that complies with all requirements, so-called "salt cell" conditions should be used in which a physical barrier prevents contact of the waste with percolating water. Unlike fly ash and APC residue, bottom ash from municipal waste incineration is also accepted in category-2 landfills, which are exclusively for non-hazardous wastes. The leaching criteria are similar to those for category-1 landfills.

No fly ash or APC residue from waste incineration is recycled in Flanders. These residues are landfilled in category-1 landfills. The soluble salt content and the lead leachability exceed the limit values for disposal in category-1 landfills; therefore, fly ash and APC residue have to be treated before disposal. Adding cement is a common technique but cannot always reduce Pb leaching to below the limit value. Other immobilisation recipes then have to be applied. These additives, however, do not reduce the soluble salt content to below the 10% limit value. So-called salt cell conditions are therefore needed to prevent contact with percolating water (Geysen et al., 2004a,b).

4. Legislation and waste management in neighbouring regions or countries

4.1. The Walloon region

In 2001 Wallonia (population = 3.35 million) collected 53% of its MSW selectively, which leaves 650,000 tons of solid waste to be terminally removed. Of this amount, 28% was incinerated in 4 incinerator installations, resulting in about 37,000 tons of bottom ash (CEE, 2003).

4.1.1. Recycling

In Wallonia bottom ash, fly ash and APC residue can be labeled as either hazardous or non-hazardous, depending on the total content of, among others, heavy metals. In practice, bottom ash is assumed to be non-hazardous, while fly ash and APC residue are considered possibly hazardous. The latter are therefore not included in the list of wastes that are eligible for recycling. Bottom ash does appear on this list and can be recycled as such in foundation constructions or as an aggregate in concrete. However, of all materials on the list, bottom ash is the most rigorously tested. Leaching of either application (as such or as aggregate in a monolith) has to comply with a set of limit values using the NEN7343 column test and with a set of limit values using the DIN38414-S4 extraction test (Table 2). These limit values are specifically to be used in the case of bottom ash.

4.1.2. Landfilling

The Walloon region has established three main classes of landfills: class-1 landfill accepts hazardous wastes, class-2 is for the disposal of non-hazardous industrial and municipal waste, and class-3 for inert waste. Besides these categories, landfills exist for dredging sludge (class-4) and for exclusive use by one waste producer (class-5). To date no limit values exist as acceptance criteria for waste. Acceptance is based on the broad definitions of hazardous, non-hazardous and inert waste. Fly ash and APC residue should be landfilled in a class-1 landfill. Wallonia, however, does not have such a landfill (CEE, 2003). These residues are then either transported abroad or treated in order to landfill them in class-2 landfills (MRW, 1998).

4.2. The Netherlands

In the Netherlands (population = 16 million), 11 large MSW-incinerators incinerate about 5 million tons

Table 3
Limit values for disposal of hazardous (H) and non-hazardous (NH) waste in selected countries

Category	Flanders		The Netherlands	Germany			France			European Union[a]					
	II	I	C_3	Z_3	Z_4	Z_5	I	IA	IB	Non-hazardous			Hazardous		
Waste	NH	NH/H	H	NH	NH	H	H	H	H	NH/H			H		
Test	DIN[b] extr.	DIN[b] extr.	NEN column	DIN[b] extr.	DIN[b] extr.	DIN[b] extr.	NFX extr.	NFX extr.	NFX extr.	EN extr.	EN extr.	EN[b] column	EN extr.	EN extr.	EN[b] column
L/S	10	10	1	10	10	10	30	30	30	2	10	0.1	2	10	0.1
As	10	10	9	2	5	10	10	30	30	0.4	2	3	6	25	30
Ba	–	–	60	–	–	–	–	–	–	30	100	200	100	300	600
Cd	5	5	0.2	0.5	1	5	25	100	50	0.6	1	3	3	5	17
Co	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–
Cr	–	–	30	–	–	–	50	100	100	4	10	25	25	70	150
Cr^{VI}	5	5	–	0.5	1	5	5	30	20	–	–	–	–	–	–
Cu	100	100	10	10	50	100	–	–	–	25	50	300	50	100	600
Hg	1	1	0.1	0.05	0.2	1	5	10	10	0.05	0.2	0.3	0.5	2	3
Mo	–	–	3	–	–	–	–	–	–	5	10	35	20	30	100
Ni	20	20	10	2	10	20	50	100	100	5	10	30	20	40	120
Pb	20	20	25	2	10	20	50	2000	100	5	10	30	25	50	150
Sb	–	–	0.8	–	–	–	–	–	–	0.2	0.7	1.5	2	5	10
Se	–	–	0.3	–	–	–	–	–	–	0.3	0.5	2	4	7	30
Sn	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–
V	–	–	20	–	–	–	–	–	–	–	–	–	–	–	–
W	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–
Zn	100	100	40	20	50	100	250	500	500	25	50	150	90	200	600
Br^-	–	–	160	–	–	–	–	–	–	–	–	–	–	–	–
Cl^-	10,000	–	50,000	–	–	100,000	–	–	–	10,000	15,000	85,000	17,000	25,000	150,000
F^-	500	500[c]	280	50	250	500	–	–	–	60	150	400	200	500	1200
SO_4^{2-}	10,000	–	80,000	–	–	50,000	–	–	–	10,000	20,000	70,000	25,000	50,000	170,000
CN^-	10	10	5	–	–	–	5	10	10	–	–	–	–	–	–
Free CN^-	–	–	3	1	5	10	–	–	–	–	–	–	–	–	–
NO_2^{--}	300	300		–	–	300	–	–	–	–	–	–	–	–	–
NH_4^+	–	10,000[c]		40	250	10,000	–	–	–	–	–	–	–	–	–
pH	–	4–13	3–13	5.5–13	5.5–13	4–13	4–13	4–13	4–13	>6	>6	>6	–	–	–

All values are expressed in mg/kg dry matter for the sake of comparison, although formal values are sometimes in mg/l.
[a] The limit values given in European legislation should be consulted together with the many exceptions that are made possible in the legislative articles.
[b] Formal limit values are expressed in mg/l but are recalculated to mg/kg by multiplication with the applied *L/S* ratio.
[c] Indicative value.

of solid waste per year. This leads to more than 1 million tons of bottom ash and 150,000 tons of APC residue and boiler ash (Lamers and van Aalten, 2001).

4.2.1. Recycling

It is the Dutch aim to responsibly maximize recycling of MSWI residues and avoid landfilling as much as possible. The Netherlands are pioneers in recycling waste for construction applications. Waste can be recycled in granular or in monolithic applications. Waste can be applied as construction material when immission into the soil of selected compounds is below limit values (Table 2). The immission values have to be calculated from test results obtained with the NEN7345 diffusion test for monolithic applications and with the NEN7343 column test for granular applications. The result of this calculation depends on where and how much of the material is applied. When the material complies with the immission limit values for category-1 construction material, it is classified as such and no isolation precautions are needed to prevent contact with water. When the immission limit values for category-1 are exceeded, but category-2 limit values are complied with, the waste can be recycled as category-2 construction material provided all necessary isolation measures are taken.

Bottom ash from waste incineration does not, even after isolation measures, comply with the immission limit values for copper, molybdenum and antimony (KIWA, 1999) and thus does not comply with the demands for category-2 construction material. Since large-scale landfilling of bottom ashes is an undesirable option in Dutch policy, the MSWI sector has been summoned to improve the quality of the residues through upgrading. As development and implementation of upgrading techniques will take time, a special category with adjusted, less stringent limit values is temporarily created so that these bottom ashes can in the intermediate period be recycled (BA in Table 2). Extra isolation measures have to be taken in comparison with category-2 construction material. This special category for bottom ashes will cease to exist on 31 December 2005. When the bottom ash complies with the requirements of the special category, a recycling certificate is delivered. This implies that a guideline for recycling of bottom ashes with recycling applications and control protocols has to be followed.

Until 2002 all bottom ashes from waste incineration have been recycled as foundations or as embankment for road or railway construction (Lamers and van Aalten, 2001). Bottom ashes are sieved in fractions <10–12, <40 and >40 mm. The fraction >40 mm is crushed and sieved again. Iron scrap and non-ferrous materials are removed. The different fractions have to age for at least six weeks before use. In 2000, 280,000 tons of treated bottom ashes complied with the requirements for category-2 construction material, and 630,000 tons were considered as special category MSWI-bottom ashes. Due to the number of large-scale constructions in which bottom ash can be utilized, the demand in the years 2000–2001 has been such that even bottom ash from Belgium was accepted for treatment and used in The Netherlands for construction applications.

4.2.2. Landfilling

Recycling of fly ash and APC residue is not possible because limit values are exceeded even with isolation measures; these incinerator wastes have to be landfilled. Hazardous wastes have to be landfilled on a C_2 or C_3 landfill. The selection of the landfill category depends on the leachability of several compounds following the short NEN7343 column leaching protocol with $L/S = 1$. Limit values are given in Table 3. If concentrations in the leachate are below the limit values, the waste is categorized as C_3. If one or more of the leaching values are above or equal to the corresponding limit values, the waste has to be categorized as C_2. C_1 waste is a collection of very specific hazardous wastes, e.g. Hg-containing waste, untreated As_2S_3 sludge, etc., for which The Netherlands does not have landfilling capacity. In The Netherlands there is one landfill specifically for C_2 wastes, which is a concrete bunker with a capacity of 230,000 tons hazardous waste, and several C_3 landfills.

Since 1999 landfilling of fly ash and APC residue without prior treatment has been prohibited. These wastes can be stored in C_3 landfills in compartments that are made suitable for accepting C_2 wastes or in compartments that are made suitable for immobilized wastes. In addition, one-fifth of the fly ash from waste incineration is recycled as asphalt filler (containing 25% of fly ash). Besides landfilling and recycling as filler in asphalt, fly ash is also exported from The Netherlands to Germany and dumped there as stabilization material for preventing the collapse of salt mines and for filling up old coalmines.

4.3. Germany

4.3.1. Recycling

In Germany, wastes are divided in 7 categories depending on the composition and the leachability according to the DIN38414-S4 leaching protocol. The categories are Z_0, $Z_{1.1}$, $Z_{1.2}$, Z_2, Z_3, Z_4 and Z_5. The limit values are given in Tables 2 and 3. Z_0 wastes can be recycled as construction material without any limitation. $Z_{1.1}$, $Z_{1.2}$ and Z_2 waste have more limited use: $Z_{1.1}$ can be used in hydrologically unfavourable conditions, $Z_{1.2}$ in hydrologically favourable conditions and for Z_2 wastes, technical protection measures have to be taken.

Bottom ashes can be recycled for road construction. Besides the above-mentioned categories, a special category for bottom ashes has been created (BA in Table 2), since leaching of salts from MSWI ashes cannot

comply with Z_2 limit values. When recycling is not possible, the bottom ashes should be landfilled as non-hazardous waste.

4.3.2. Landfilling

Z_3 wastes must be landfilled in category-1 landfills, Z_4 waste in category-2 landfills and Z_5 wastes in landfills for hazardous materials. Both category-1 and -2 landfills are for non-hazardous waste, but category 2 is for wastes that have a higher leachability than wastes in category 1. Landfills for hazardous waste can be above ground or underground in salt mines. When hazardous wastes do not comply with the Z_5 limit values, they have to be treated or stored in underground salt mines in big bags.

The German legislation has identified refilling old mines as a useful application for fly ashes and APC residues. This approach has been criticized, because the long-term consequences are less clear (Gebers and Küppers, 1998; Schmitz and Wermuth, 2001).

4.4. France

4.4.1. Recycling

Three types of recycling are distinguished, based on the NFX31-210 extraction test (Table 2). Bottom ash with a low leachability is of the V-type (valorization) and can be recycled immediately in road and other constructions without taking isolation measures. M-type bottom ash (maturation) has a medium leachability and needs treatment before recycling. This treatment can be solidification with a hydraulic binder such as cement, or ageing. Without treatment this waste has to be landfilled in a category-II landfill. Bottom ash with a too high level of leachability belongs to the S-type (storage) and has to be landfilled in a category-II landfill with prior stabilization if needed. Limit values are given for only six elements.

4.4.2. Landfilling

Incinerator residues that are not recycled, are to be landfilled in a category-I or -II landfill. Category-I landfills are for hazardous inorganic industrial waste, category-II landfills for non-hazardous organic waste. Industrial waste that has to be stabilized in order to comply with the leaching limit values for a category-I landfill (Table 3) can be temporarily stored before treatment. Depending on their leachability, which is to be tested with the NFX31-210 extraction test, these stored wastes have to be treated within two (category IA) or five (category IB) years. The limit values for identifying waste as IA or IB depend on the type of waste and are given for incinerator residues in Table 3. Fly ash and APC residue have to be landfilled in a category-I landfill. Non-recyclable bottom ash has to be landfilled in a category-II landfill, more specifically in a category-IIE2. Other types of category-II landfills are for other wastes like plastic, metal and glass (IIE1), other mineral wastes (IIE3), etc.

5. European legislation

The recycling of incinerator residues is not yet regulated at the European level.

The European Union however has recently developed and implemented a policy on landfilling of wastes. Two landfill types are applicable to incinerator residues. On the one hand, there are landfills for non-hazardous wastes including municipal waste and other non-hazardous waste. Also stable non-reactive hazardous waste (e.g., solidified waste) that complies with the acceptance criteria of the landfill can be disposed of in this landfill. On the other hand there are landfills or underground storage facilities for hazardous wastes. The European Directive, which came into effect in July 1999, establishes licensing criteria of landfills and acceptance procedures for accepting waste at these landfills. Leaching criteria were published in a Council Decision of January 2003, taking effect on July 16, 2004. The leaching criteria however will only take effect a year later on July 16, 2005. Table 3 shows the limit values for the two types of landfill. These values are for granular waste. The member states should establish criteria for monolithic waste to provide the same level of environmental protection given by the limit values for granular waste. The European Union also leaves it up to the member states to decide which of the three permitted leaching tests are used: an extraction test with $L/S = 2$ (EN12457-1/3), an extraction test with $L/S = 10$ (EN12457-2/4) or a short column test with $L/S = 0.1$ (prEN14405). Instead of the prEN14405 draft standard procedure, member states can also use national procedures approved by the European authorities.

6. Practical evaluation of a bottom ash and fly ash in view of recycling and disposal

6.1. Materials and methods

A treated bottom ash fraction from a municipal solid waste incinerator in Flanders was chosen for its high leachability of several heavy metals and was tested for its recycling possibilities as a granular material. A fly ash from an electrostatic precipitator in an industrial waste incinerator in Flanders was tested for its compliance with the landfill limit values of the different national legislations. The fly ash was immobilized with up to 40% of cement (CEM I 42.5 LA) and leached after 7 days of hardening.

Table 4
Results of column tests (mg/kg dry matter, average of 2 tests) of a bottom ash fraction compared to limit values in Flanders, Wallonia and The Netherlands (total $L/S = 10$)

	Experiment	Flanders granular	Wallonia BA	The Netherlands		
				Cat. 1	Cat. 2	BA
As	0.20	0.8	0.8	0.88	7.0	7.0
Ba	n.a.	–	–	5.5	58	58
Cd	0.01	0.03	0.03	0.032	0.066	0.066
Co	n.a.	–	0.25	0.42	2.5	2.5
Cr	0.08	0.5	0.5	1.3	12	12
Cu	**0.63**	**0.5**	5.0	0.72	3.5	24
Hg	n.a.	0.02	0.02	0.018	0.076	0.076
Mo	**0.51**	–	1.8	**0.28**	0.91	26
Ni	0.01	0.75	1.8	1.1	3.7	3.7
Pb	0.13	1.3	2.2	1.9	8.7	8.7
Sb	**0.79**	–	**0.3**	**0.045**	**0.43**	2.1
Se	n.a.	–	–	0.044	0.1	0.1
Sn	n.a.	–	–	0.27	2.4	2.4
V	n.a.	–	–	1.6	32	32
Zn	1.31	2.8	4.0	3.8	15	15
pH	8.2–9.6	–	–	–	–	–

n.a. = not analyzed.

Leaching was performed as described in an earlier paragraph. All leachates were acidified with concentrated HNO_3 and subsequently analyzed for metal concentrations using a VG PlasmaQuad PQ-2 Plus ICP-mass spectrometer.

6.2. Results and discussion

6.2.1. Leaching experiments for recycling of a bottom ash fraction

Recycling of the bottom ash fraction was tested with the NEN7343 column test (with a total $L/S = 10$) for comparison with limit values in Flanders, Wallonia and The Netherlands and with the DIN and NFX extraction tests for comparison with limit values in Wallonia, Germany and France.

Table 6
Results of NFX extraction tests (mg/kg dry matter, average of 2 tests) of a bottom ash fraction compared to limit values in France

	Experiment	V	M
As	n.a.	2.0	4.0
Cd	0.3	1.0	2.0
Cr^{VI}	0.1[a]	1.5	3.0
Hg	n.a.	0.2	0.4
Pb	0.2	10	50
pH	10.0–10.3	–	–

n.a. = not analyzed.
[a] This is total Cr.

The results are summarized in Tables 4–6. Leaching exceeded the Flemish limit value for Cu (Table 4). Ageing of the bottom ash fraction for three months decreases Cu leaching to below the limit value (Jaspers, 2002; Vandecasteele et al., 2002). In The Netherlands, this bottom ash fraction would exceed the leaching limit values for Category I in the case of Mo and Sb and for Category II in the case of Sb. There would be no problem for recycling in the special category for bottom ashes. In Wallonia, there is only a problem with Sb in the column test. In the extraction test there is no exceedance (Table 5). However, the results for both the column test and the extraction test need to comply with the limit values. The bottom ash fraction is not suitable for recycling in Germany: the limit values are exceeded for Z_0 with unrestricted reuse (As, Cd, Cr and Pb), $Z_{1.1}$, which allows reuse in hydrologically unfavourable conditions (As, Cd and Cr), $Z_{1.2}$ allowing reutilization in hydrologically favourable conditions (As and Cd), Z_2 where isolation measures need to be taken (As and Cd) and even for the special category for bottom ashes (Cd). In France immediate recycling is possible (Table 6).

The results of the column test and the two extraction tests differ substantially. This is mainly due to the difference in pH and whether or not agitation is applied.

Table 5
Results of DIN extraction tests (mg/kg dry matter, average of 2 tests) of a bottom ash fraction compared to limit values in Wallonia and Germany

	Experiment	Wallonia BA	Germany				
			Z_0	$Z_{1.1}$	$Z_{1.2}$	Z_2	BA
As	**0.8**	1.0	**0.1**	**0.1**	**0.4**	**0.6**	–
Cd	**0.3**	1.0	**0.02**	**0.02**	**0.05**	**0.1**	**0.05**
Cr	**0.7**	1.0[a]	**0.15**	**0.3**	0.75	1.5	2
Cu	0.5	20	0.5	0.5	1.5	3	3
Hg	n.a.	0.2	0.002	0.002	0.01	0.02	0.01
Ni	<0.1	2.0	0.4	0.5	1.5	2	0.4
Pb	**0.3**	2.0	**0.2**	0.4	1	2	0.5
Th	n.a.	–	<0.01	0.01	0.03	0.05	–
Zn	0.1	9.0	1	1	3	6	3
pH	10.2	7–12	5.5–10[b]	5.5–12[b]	5.5–12[b]	–	7–13

n.a. = not analyzed.
[a] This is Cr^{VI}.
[b] Indicative values.

Table 7
Results of DIN extraction tests (mg/kg dry matter) of a fly ash compared to limit values in Flanders, Germany and the EU

	Experiment					Flanders	Germany	EU
	No cement[a]	+10% cement	+20% cement	+30% cement	+40% cement	Cat. I landfill	Z_5	Hazardous waste
As	4	2	03	0.4	0.2	10	10	25
Cd	**163**	**49**	0.1	0.1	<0.1	**5**	**5**	**5**
Cr	1	0.4	5	2	2	5[b]	5[b]	70
Cu	56	36	23	23	5	100	100	100
Hg	n.a.	n.a.	n.a.	n.a.	n.a.	1	1	2
Ni	14	2	<0.1	<0.1	<0.1	20	20	40
Pb	**32**	16	1	0.3	0.1	**20**	**20**	**50**
Zn	**22,000**	**420**	64	63	26	**100**	**100**	**200**
pH	6.8	8.1	11.6	12.1	12.4	4–13	4–13	–

n.a. = not analyzed.
[a] Average of 2 tests.
[b] This is Cr^{VI}.

6.2.2. Leaching experiments for landfilling of a fly ash

To evaluate whether the fly ash can be landfilled immediately or has to be stabilized, the DIN extraction test was carried out for comparison with limit values for hazardous waste in Flanders, Germany and the EU, the NEN7343 column test was used for comparison with the Dutch (total $L/S = 1$) and European (total $L/S = 0.1$) limit values and the NFX31-210 extraction test was used for comparison with French limit values.

The results are shown in Tables 7–9. The Flemish limit values for landfilling in a category-2 landfill are the same as the German Z_5 limit values for landfilling of hazardous waste. Without stabilization the fly ash cannot be landfilled as the limit values are exceeded for Cd, Pb and Zn (Table 7). In Germany this fly ash could be disposed of in salt mines stored in big bags. Addition of 20% cement is needed for compliance with the above-mentioned limit values. In The Netherlands the fly ash does not comply with the requirements of a C_3 landfill (the limit values for Cd, Co, Cu and Zn are exceeded) and has to be landfilled in a C_2 landfill or in a special compartment of a C_3 landfill (Table 8). In France Cd and Zn leaching exceeds the limit value for landfilling on a category-I landfill (Table 9). Due to the high leaching of Cd, Pb and Zn, no temporary storage of the waste before treatment can be permitted. Addition of cement as a hydraulic binder does not decrease leaching of Zn below the limit value of a category-I landfill. Other additives or techniques have to be investigated. When comparing results with the European limit values, leaching exceeds the limit values for Cd and Zn both in the extraction test (Table 7) and the column test (Table 8). Using the extraction test, 20% of cement has to be added to the waste in order to make it acceptable for disposal in a landfill for hazardous waste. This corresponds with the required treatment in Flanders and Germany.

Table 8
Results of column tests of a fly ash (mg/kg dry matter, average of 2 results) compared to the Dutch and the European limit values

	The Netherlands ($L/S = 1$)		European Union ($L/S = 0.1$)	
	Experiment	C_3-limit value	Experiment	Hazardous
As	1.3	9	23	30
Ba	n.a.	60	n.a.	600
Cd	**138**	**0.2**	**2140**	**17**
Co	**6.5**	**6**	69	–
Cr	0.8	30	16	150
Cu	**12.4**	**10**	140	600
Hg	n.a.	0.1	n.a.	3
Mo	0.6	3	8	100
Ni	7.5	10	80	120
Pb	2.6	25	42	150
Sb	0.2	0.8	3	10
Se	n.a.	0.3	n.a.	30
Sn	n.a.	6	n.a.	–
V	n.a.	20	n.a.	–
W	n.a.	0.5	n.a.	–
Zn	**9466**	**40**	**116,300**	**600**
pH	5.6–6.1	3–13	5.7	–

n.a. = not analyzed.

7. Comparison of waste management under the different legislations

Waste management in the countries considered differs at three levels. At the level of *management options*, all countries distinguish between landfilling and recycling of waste.

In Wallonia, The Netherlands, Germany and France recycling of bottom ash has been specifically regulated. Limit vales of some components are less stringent compared to the limit values required for recycling of other waste types (e.g., Cu, Mo and Sb in The Netherlands; As, Cr, Th, Cl^-, SO_4^{2-}, total CN^- in Germany), while limit values of other components have been tightened (e.g., Cd, Hg, Ni, Pb, Zn, free CN^- in Germany) in order to facilitate reuse of bottom ash. Additional precautionary measures also have to be taken. In Flanders no

Table 9
Results of NFX extraction tests (mg/kg dry matter) of a fly ash compared to French limit values

	Experiment					Landfill	Storage	
	No cement[a]	+10% cement	+20% cement	+30% cement	+40% cement	Cat. I	Cat. IA	Cat. IB
As	4.4	5.4	2.3	5.1	1.9	10	30	30
Cd	**186**	**71**	0.1	1.3	1.2	**25**	*100*	*50*
Cr	0.6	7.6	8.2	13.3	13.6	50	100	100
Cr^{VI}	n.a.	n.a.	n.a.	n.a.	n.a.	5	30	20
Hg	n.a.	n.a.	n.a.	n.a.	n.a.	5	10	10
Ni	16.1	5.6	2.5	0.4	0.2	50	100	100
Pb	**58**	31	10.9	50	**76**	**50**	2000	100
Zn	**24,771**	**5376**	**848**	**432**	**460**	**250**	*500*	*500*
pH	6.7–8.5	7.2–11.1	11.1–11.5	11.8–11.9	11.9–12.2	4–13	4–13	4–13

n.a. = not analyzed.
[a] Average of 2 tests.

specific limit values exist for bottom ash. With the very low limit value for Cu leaching, the Flemish market for bottom ash recycling is severely hampered. All countries are less inclined to recycle fly ash and APC residue than bottom ash, but The Netherlands and Germany recycle a fraction of these wastes: as filler in asphalt (The Netherlands) or as stabilization material for salt mines (Germany).

Within the landfill option, more similarities exist. All countries consider bottom ash as non-hazardous waste whereas fly ash and APC residue are considered hazardous, so that these must be disposed of in different landfills.

With regard to *leaching tests*, column tests and extraction tests are applied. While The Netherlands use a column test to test landfilling and recycling, Germany and France use an extraction test for landfilling and recycling. Flanders makes use of a column test for recycling and an extraction test for landfilling. Wallonia requires testing by means of both the column test and the extraction test for recycling options; no leaching tests are required for landfilling. The European legislation permits extraction tests as well as a short column test for landfilling as a compromise.

As to the *limit values*, limit values are available for more metals in The Netherlands than in any other country: 19 limit values for recycling and 22 for landfilling. Wallonia also has 19 limit values for recycling, but these include less critical elements such as Al and K. Germany (10-13 limit values for recycling, 11-14 for landfilling), Flanders (8 limit values for recycling, 14 for landfilling) and the EU (15 limit values for landfilling) have regulated significantly less components. France has the least limit values of the regions and countries considered, with 6 for recycling and 9 for landfilling.

It is difficult to compare limit values between countries that use different types of leaching tests. While equilibrium is assumed to have been achieved in agitated extraction tests, this assumption is much less appropriate for column tests. Within one type of leaching test, limit values and leaching results are comparable as long as the L/S ratios are equal. The following comparisons can be made, based on the limit values in Tables 2,3 and on the practical evaluation of two incinerator residues:

- Recycling of bottom ash has to be tested with the column test ($L/S = 10$) both in Wallonia and The Netherlands. The limit values in Wallonia are stricter than in The Netherlands although slightly more heavy metals are regulated in the latter. In The Netherlands extra isolation measures are needed, which are not required in Wallonia.
- According to the limit values, the investigated bottom ash can be recycled in The Netherlands (up to 2006) and France. In Flanders, Wallonia and Germany, the tested bottom ash fraction needs further treatment before recycling. The difference between The Netherlands and Flanders is in agreement with the comparison of limit values.
- For landfilling of non-hazardous waste, the Flemish limit values for category-1 landfills can be compared with the Z_3 and Z_4 landfills in Germany and with the values (EN extraction test, $L/S = 10$) for landfilling non-hazardous waste in the EU. The Flemish limit values are less stringent than the ones for Z_3 and even Z_4 in Germany, although more salts are regulated in Flanders. The EU legislation is stricter than the Flemish one, with respect to limit values, and comparable with the Z_4 category in Germany, although more components (both heavy metals and salts) are regulated in the EU.
- The values for the Category-1 landfill in Flanders are equal to the values for the landfill for hazardous waste in Germany (both DIN extraction test, $L/S = 10$), except for salts where Germany has more components regulated. The limit values for hazardous waste set forth in the European legislation are less stringent than the ones in Flanders and Germany, although more heavy metals are regulated in the EU.

With respect to the investigated fly ash, it could be disposed of in The Netherlands in a C_2 landfill or in a special compartment of a C_3 landfill and in Germany in salt mines. In Flanders, Germany and following the EU legislation, 20% of cement must be added to the fly ash in a solidification/stabilisation process in order to make it acceptable in a landfill for hazardous waste. In this particular example, the EU is as stringent as Flanders and Germany. In France solidification/stabilisation with up to 40% cement would not suffice to make the waste acceptable in a landfill for hazardous waste; in this case another pretreatment is necessary.

The differences in legislation between the European countries may lead to both legal and illegal transport of important quantities of waste between European countries. In order to prevent illegal activities with possibly catastrophical consequences for the environment and human health, harmonization of legislation is needed. To date it is mainly the landfilling legislation that is moving towards harmonization. European legislation on recycling should also be developed soon as the market for recycling can be rapidly increasing nationally as well as internationally.

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Appendix A

The consulted legislation is listed hereafter for each country or region.

A.1. Flanders

- Decreet van 2 juli 1981 (gewijzigd in 1994) betreffende de voorkoming en het beheer van afvalstoffen
- Besluit van de Vlaamse Regering van 1 juni 1995 (laatst gewijzigd in 2002) houdende algemene en sectorale bepalingen inzake milieuhygiëne (Vlarem II)
- Vlaams Reglement van 17 december 1997 (volledig herzien in 2004) inzake afvalvoorkoming en –beheer van 1998 (Vlarea)

A.2. Wallonia

- Décret du 27 juin 1996 relatif aux déchets (dernière modification le 16 octobre 2003)
- Arrêté du Gouvernement wallon du 10 juillet 1997 établissant un catalogue des déchets (modifié le 24 janvier 2002)
- Arrêté du Gouvernement wallon du 14 juin 2001 favorisant la valorisation de certains déchets (modifié le 27 mai 2004)
- Arrêté du Gouvernement wallon du 4 juillet 2002 arrêtant la liste des projets soumis à létude dincidences et des installations et activités classées
- Arrêté du Gouvernement wallon du 27 février 2003 fixant les conditions sectorielles dexploitation des centres denfouissement technique (modifié le 18 mars 2004)

A.3. The Netherlands

- Bouwstoffenbesluit bodem- en oppervlaktewateren-bescherming van 23 november 1995
- Uitvoeringsregeling Bouwstoffenbesluit van 30 januari 1998 (gewijzigd op 5 oktober 2000)
- Stortbesluit bodembescherming van 20 januari 1993 (gewijzigd op 5 januari 1998)
- Besluit stortplaatsen en stortverboden afvalstoffen van 8 december 1997 (laatst gewijzigd op 13 juli 2001)

A.4. Germany

- Abfallgesetz
- Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Beseitigung von Abfällen
- Verordnung zur Bestimmung von überwachungsbedürftigen Abfällen zur Verwertung
- TA-Siedlungsabfall
- TA-Abfall
- LAGA Mitteilungen, Anforderungen an die stoffliche Verwertung von mineralischen Reststoffen/Abfällen – Technische Regeln

A.5. France

- Arrêté du 18 décembre 1992 rélatif au stockage de certains déchets industriels ultimes et stabilisés pour les installations existantes
- Arrêté du 18 décembre 1992 rélatif au stockage de certains déchets industriels ultimes et stabilisés pour les installations nouvelles
- Arrêté du 9 septembre 1997 rélatif aux décharges existantes et aux nouvelles installations de stockage des déchets ménagers et assimilés.

- CIRCULAIRE DU 9 MAI 1994 RÉLATIVE À LÉLIMINATION DES MÂCHEFERS DINCINÉRATION DES RÉSIDUES URBAINS

A.6. The European Union

- DIRECTIVE 1999/31/EC OF 26 APRIL 1999 ON THE LANDFILL OF WASTE
- COUNCIL DECISION 2003/33/EC OF 19 DECEMBER 2002 ESTABLISHING CRITERIA AND PROCEDURES FOR THE ACCEPTANCE OF WASTE AT LANDFILLS

References

CEE (Cellule État de l'Environnement), 2003. Tableau de bord de l'environnement wallon. MRW – DGRNE, Jambes, Belgium.

Cortvriend, D., 2001. Nuttig hergebruik van bodemassen – Situatieschets vanuit een Belgisch perspectief. In: Proceedings, 21ste Seminarie over Het Beheer van Afvalstoffen, 7–8 november 2001. VUB, Brussels, Belgium..

Gebers, B., Küppers, P., 1998. Hintergrunddossier, Die zweifelhaften Erfolge der Verwertung in Deutschland, Beispiel: Abfälle als Bergversatz. Öko-Institut e.V., Freiburg, Germany.

Geysen, D., Imbrechts, K., Vandecasteele, C., Jaspers, M., Wauters, G., 2004a. Immobilization of lead and zinc in scrubber residues from MSW combustion using soluble phosphates. Waste Management 24, 471–481.

Geysen, D., Vandecasteele, C., Jaspers, M., Wauters, G., 2004b. Comparison of immobilisation of air pollution control residues with cement and with silica. Journal of Hazardous Materials B 107, 131–143.

IAWG, 1997. Municipal solid waste incinerator residues. Studies in Environmental Sciences 67. Elsevier, Amsterdam, The Netherlands.

Jaspers, M., 2002. Treatment of bottom ashes from waste incineration by the wet process: the Indaver case. In: Wauters, G., Vandecasteele, C. (Eds.), Annual Symposium on the Technical Aspects of Hazardous Waste Incineration, 27–29 November 2002, Leuven, Belgium.

KIWA, 1999. Nationale Beoordelingsrichtlijn voor het KOMO attest-met-productcertificaat voor AVI-bodemas voor ongebonden toepassing op of in de bodem in grond-en wegenbouwkundige werken. BRL2307, Rijswijk, The Netherlands.

Lamers, F., van Aalten, J., 2001. Management of municipal solid waste incineration residues in The Netherlands. In: Proceedings, 21ste Seminarie over Het Beheer van Afvalstoffen, 7–8 November 2001. VUB, Brussels, Belgium.

MRW (Ministère de la Région wallonne), 1998. Horizon 2010 – Plan Wallon des déchets. Namur, Belgium.

OVAM, 2001a. Tarieven en capaciteiten voor storten en verbranden – Actualisatie tot 2000, evolutie en prognose. Mechelen, Belgium.

OVAM, 2001b. Inventarisatie van de afvalverbrandingssector in Vlaanderen. D/2001/5024/7. Mechelen, Belgium.

OVAM, 2003. Personal communication with B. Thibau.

Schmitz, K., Wermuth, B., 2001. Disposal of inert hazardous waste in surface and underground waste disposal sites – an ecological approach. In: Christenen, T.H., Cossu, R., Stegmann, R. (Eds.), Eighth International Waste Management and Landfill Symposium, 1–5 October 2001, San Margherita di Pula, Sardinia, Italy.

Vandecasteele, C., Imbrechts, K., Van Gerven, T., Geysen, D., Jaspers, M., Wauters, G., 2002. Optimization of the quality of bottom ashes. In: Wauters, G., Vandecasteele, C. (Eds.), Annual Symposium on the Technical Aspects of Hazardous Waste Incineration, 27–29 November 2002, Leuven, Belgium.

Vrancken, K., Laethem, B., Dutré, V., 2000. Valorisation of MSW incineration residues in Belgium: a developing market. In: Dhir, R.K., Dyer T.D., Paine, K.A. (Eds.), Proceedings of the International Symposium of Sustainable Construction: Use of Incinerator Ash, 20-21 March 2000, Dundee, UK.

VMM, 2002. Milieu- en Natuurrapport Vlaanderen: thema's, MIRA-T 2002. D/2002/5779/151. Garant, Antwerpen, Belgium.